The Economics of Technologies in Swedish Pig Production

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Abstract

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Decisions on technologies, at farm and enterprise levels, have major implications for the biological performance in livestock production, and thereby on the economic benefits of production. However, when existing exogenous conditions are subject to change and influence the economic situation at farm level, the farmer needs to reconsider decisions on the composition of the technology set in order to improve productive performance and profit. The common aim of this thesis relates to the use of specific technologies in Swedish pig production including building design, feeding system, and managerial practices. Hence, a major aim is to analyse the economic value of technologies, considering animal welfare legislation and environmental regulations on production externalities.

The thesis consists of four different articles, two of which them concern methods for assessment of the value of technologies. Article I, The value of animal welfare improving technologies in Swedish pig production, assesses the economic value of specific production technologies. Article II, Technology effects on pigs' feed efficiency, analyses specific technology effects on the quantity of pig meat produced and variance as affected by a change in feed use. The other two articles concern the economic implications of technology use in relation to production externalities. Article III, Utility of phase feeding choices in pig farming, ranks farmers' utility of using different protein contents in feed taking into account externalities from organic manure. Article IV, Environmental regulations with focus on pig density restriction and farms' technologies, analyses the effects of the pig density regulation on intensive pig farming. The effects of several technologies on the cost of altering production to comply with environmental regulations are examined.

A major conclusion of this thesis is that an economically rational farmer considers the value of specific technologies that frequently may improve animal welfare, and in some cases also reduce production externalities. However, the economic value and the biological benefits obtained from a given technology vary depending on individual conditions at farm level.

Key words: Dynamic system, stochastic processes, profit maximisation, expected utility maximisation, utility of alternative choices, opportunity cost, adoption of technologies.

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Preface

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Articles appended to the thesis

This thesis is based on the following articles:

I Campos, M. and Andersson, H. The value of animal welfare improving technologies in Swedish pig production. Submitted to European Review of Agricultural Economics.

II Campos, M. Technology effects on pigs' feed efficiency. Submitted to European Review of Agricultural Economics.

III Campos, M. Utility of phase feeding choices in pig farming. Submitted to Journal of Agricultural Economics.

IV Campos, M. Environmental regulations with focus on pig density restriction and farms' technologies. Submitted to Journal of Agricultural Economics.

Contents

Background

The Swedish agricultural sector has been highly regulated since the 1930's. Policy measures have been primarily designed to guarantee farmers' income and to ensure a high level of self-sufficiency in agricultural production (Ds, 1989:63). Until the late 1980's market prices were been determined through negotiations between the government, farmers and consumers (Rabinowicz and Bolin, 1986). In 1992, Sweden and EU-countries enacted a major agricultural reform (SJV, 2001b). The underlying reason for the deregulation was to reduce existing surplus production and to reduce subsidies on producer prices (Ds, 1989:63). Farmers are instead directly compensated through subsidies based on the acreage of land and number of animals.

The trend for the producer prices during the 1990's shows a pattern of decay in Sweden and EU-countries, as presented in table 1. However, the producer price level is decreasing at a faster rate in Sweden compared to other EU-countries leading to unfavourable economic conditions for Swedish farmers in the international market (SJV, 2001a).

Table 1: Indices of producer prices for Sweden and EU-countries, 1990 – 2000.

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Sweden	100	100.1	96.6	92.8	97.6	97.8	93.9	91.3	92.3	89.7	88.2
EU-countries	100	102.5	98.5	97.2	100.7	104.8	105.3	103.8	101.2	97.7	101.1

Source: Swedish Board of Agriculture, report 2001:15.

As shown in table 2, during the 1990's the same decaying trend of producer prices is observed for the Swedish pig industry. The trend is further accentuated when Sweden joins the EU in 1995. One reason for the relatively low producer prices is excess production of pig meat in international markets (SJV, 2001b). Until 1995 animal feed prices decrease over time at a faster rate than producer prices. However, after 1995 the relative price of feed compared to producer prices increases.

Table 2: Indices of pig producer prices and animal feed prices for Sweden, 1990 – 2000.

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Producer prices	100	104.0	96.0	96.7	99.0	89.3	95.6	100.2	82.4	77.0	87.4
Feed prices	100	97.7	96.9	94.6	91.4	89.4	101.2	103.8	96.8	91.8	94.3

Source: Swedish Board of Agriculture, report 2001:15.

The pig industry has been characterised by excess production during the 1990's except for 1992 and 1995 when pig meat consumption exceeded than domestic production (see table 3). During the 1990's the trend for pig meat production is increasing. During this period, farmers receive export subsidies and subsidies to store pig meat (SJV, 2001b). However, the decay in international prices affects the export revenues of pig meat.

Table 3: Pig meat production and consumption (in million kg) for Sweden, 1990 – 2000.

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Production	291	268	278	291	308	311	321	329	330	325	277
Consumption	262	266	283	283	299	314	309	314	328	318	316

Source: Swedish Board of Agriculture, report 2001:21.

International and domestic market conditions during the 1990's may be an explanation to structural changes in the pig sector. According to table 4, the number of pig farms decreases drastically between 1990 and 2000, while the average size of herds during the same period increases. Structural changes turn traditional small-farm pig production into large-size intensive system, implying that many farmers exit the industry during this period (Hoffmann *et al*., 1997).

Table 4: Number of pig farms and average size of pig herds during 1985 – 2000.

Year	1985	1990	1995	2000
Number of farms	19937	14301	10753	4809
Average size of herds	95	119	157	294

Source: Statistics Sweden, 2002.

The unfavourable economic conditions and the structural changes in the pig sector are accompanied by rather stringent animal welfare legislation (SFS, 1988:534). The objective of animal welfare legislation is to protect animals from avoidable suffering, to promote animals' health, and to raise animals in an appropriate environment, adhering to their natural behaviour (Prop, 1987/1988:93). Some of the prescribed production measures regard building design, animal transport and slaughtering methods. Guidelines on building design include regulations designed towards climate conditions in the stable, low noise level and windows providing daylight (*Ibid*). For instance, boxes must be spacious with access to straw-beds, in order to promote animals' natural behaviour and to protect them from any harm and infection risks.

Structural change in the pig sector implies higher pig density. Intensive livestock farming, in limited areas can be a problem leading to higher emission levels to the environment. In Sweden there are especially designed regulations at the farm level, on manure handling (SFS, 1998:915), and regulations concerning the allowable animal density levels (SJVFS, 1999:79). Regulations on manure handling provide regional distinctions according to pig density level and the environmental features of a region such as soil quality and water sources (SJV, 2000). Depending on the kind of livestock production, manure can be stored in basins up to ten months. Furthermore, there are specific regulations regarding the design of store basin such as coverage, recommendations concerning leaching levels, how to and when to spread manure on croplands. Regulations on the allowable animal density define the maximum number of animals per hectare that can be produced depending on the kind of animal. The main objectives with these regulations are to reduce nitrogen leakage and ammonia volatilisation arising from human activities in order to preserve landscape biodiversity (SOU, 1997:102; 1999:78).

1 Introduction

During the 1990's pig farmers face structural changes and legal regulations, leading to the need for new managerial decisions. Decisions at herd and production level become more important due to the economic conditions and the necessity of adjusting to the new technological requirements where production performance conforms to animal welfare and environmental regulations. Important for intensive livestock farming is the control of the animal's nearby environment.

The developments of infection and stress symptoms have a direct influence on animal growth and feed consumption, affecting farmers' profitability. For some farms a change from an extensive to more intensive operations have been successful since a more advanced technology is introduced. Feed automatisation, for instance, offers a more balanced nutritional diet, thereby reducing feed waste (Mattsson, 1998). However, typical for pig production is that is not necessary to increase farm land-size to increase pig density per ha, since feed can be purchased. Hence, in geographically limited production areas intensive pig farming may imply higher emission levels leading to environmental problems due to limitations of nature in assimilating nutrient overloads.

Consequently, when a farmer selects a technology he must simultaneously take into account: (1) effects on biological performance; (2) prescribed regulations on animal welfare and production externalities; and (3) profitability. A technology that improves animal welfare may have positive effects on biological performance. A positive change in biological performance has positive effects on profit. Furthermore, improved biological performance at an optimal feed intake implies less feed waste thereby reducing production externalities to the environment.

1.1 The economic problem

Traditional pig production has turned from small-size farms into large-size intensive systems. In addition to a by international standards, rather stringent animal welfare and environmental legislations farmers are forced to reconsider decisions on the composition of the production technology set. However, the implementation of a new technology set involves uncertainty on its effects in the conversion of inputs into output (Ramaswani, 1992). Hence, suboptimal behaviour given vulnerable economic conditions may also affect the economic strength of the farms.

Several studies on livestock production investigate specific technology effects on daily weight gain and feed consumption (Simonsson *et al*., 1997), animal welfare (Ewing *et al*., 1999), and production externalities arising from manure handling (Steineck *et al*., 2001). However, these studies do not consider the relation between the use of a production technology and its economic benefits. Studies on livestock production focus on the biological process of production rather than profit maximisation in the problem statement. Conversely, economic studies on livestock production frequently regard technologies as constants, disregarding the value of specific production technologies. Azzam (1998) addresses the importance of using specific information on fixed costs, such as investments in technologies.

There are many economic studies concerning pig production. However, there is a lack in the literature concerning the economic values of specific technologies and the implications for animal welfare and production externalities.

1.2 Literature review

Models in this thesis are based on microeconomic methodology concerning production, optimal control theory and the statement of maximisation problems and revealed preferences. The vast literature of applied production economics includes Chambers (1988), which offer a useful exhibition on the specification of production functions, profit functions, and the role of technologies in production. When modelling dynamic systems Chiang (1992) and Dorfman (1969) offers a good exposition on optimal control theory. Issues on optimal input decisions rest on the theory of expected utility of profit. A good introduction to expected utility theory is in Arrow (1971). Varian (1992) presents the revealed preference approach as an alternative to modelling economic problems as maximisation problems.

Animal production can be modelled by a biological production function where animal growth depends on variable inputs such as feed use. Chavas *et al*. (1985) and Boland *et al*. (1998, 1999) consider a biological relationship to describe animal production rather than a classical economic formulation including capital and labour. The approach is motivated since a change in feed input has a greater effect on animal weight gain than a change in capital or labour has. Chavas *et al*. (1985) relate animals' growth to feed consumption in addition to further nutritional information. Boland *et al*. (1999) explain pigs' growth considering different feed nutrient ratios.

Studies on optimal input decisions characterised by a stochastic process have been a highlight in production economics. Interesting topics have been demand for crop insurance (Babcock and Hennessy, 1996), fertiliser use (Smith *et al*., 1985), and biological growth (Tveterås, 1999). Studies on production efficiency recognise farm- and time-specific effects to explain the systematic part of a stochastic process. Sharma *et al*. (1996) show that differences in production efficiency across pig farms depends on differences in managerial practices. Stoneman and Kwon (1996) study the relationship between firm profitability and the adoption of technologies in the engineering industry. They show that no adopters experience reduced profits as other firms that adopt new technologies. They also show that the gains to adopters are related to firm and industry characteristics, the number of other users of new technologies, and the cost of acquisition.

Studies on the dynamics of animal production include Rasmussen (1976), Chavas *et al*. (1985), Kure (1997), and Boland *et al*. (1998, 1999). Rasmussen (1976) states a discrete time problem to study optimal replacement conditions in animal production with calculus of variation theory. However, more recent studies on optimal replacement time utilise optimal control theory (Chavas *et al*., 1985; Kure, 1997). The formulation of optimal control problems allows the specification of continuous time during a period (Chiang, 1992). In a time sequence, pig production is not continuous. When a batch is terminated and pigs marketed it is necessary to clean and disinfect the stable, which is time demanding. However, production is continuous as long as pigs are in a batch.

Previous studies on environmental policy regulations, at farm levels, suggest that a good environmental policy must minimise environmental abatement costs, it must minimise the cost producer face to reduce externalities, and it must minimise administrative cost to enforce the policy (Weersink *et al*., 1998). Shapiro and Petchey (1995) suggest that the role of government institutions in environmental policy regulations is to protect the welfare of groups not represented in a decision process. Hötte *et al*. (1995) point out that few studies take into account individual farm characteristics in relation to environmental regulation. Metcalfe (2000) concludes that in practice emissions to the environment essentially depend on how production is managed in accordance with environmental characteristics around the farm. Thus, given the findings in the literature, it seems that farmers need an economic incentive to change production conditions in order to reduce emission levels. Boland *et al*. (1998, 1999) recognise the importance of phase feeding in production, the adjustment of protein contents in feed as pigs grow, especially when farmers are land-constrained. Externalities arise from the very moment that manure is produced through nitrogen volatilisation and they continue after manure has been applied onto land through nitrogen leaching (Steineck *et al*., 2001). Brady (2003) develops a theoretical model to investigate the substitutability of organic manure and commercial fertiliser in crop and pollution production. He found that there is no perfect substitution between organic and commercial fertiliser. However reduction of manure quantity is a certain alternative to reduce leaching, justifying improved manure handling during production.

1.3 The aim of this thesis

The common aim of this thesis relates to farmers' decisions on specific technologies in relation to animal welfare and environmental regulations. Hence, the major objective of this thesis is to analyse the economic value of technologies for Swedish pig farms, considering animal welfare and environmental regulations.

The aim of this thesis is analysed in four different articles, which can be divided in two parts. The first part consists of two articles concerning the assessment of economic values of technologies in production. Technologies include building design, feeding systems and managerial practices. Article I, *The value of animal welfare improving technologies in Swedish pig production*, aims to assess the economic value of specific production technologies. Article II, *Technology effects on pigs' feed efficiency*, aims to analyse specific technology effects on the quantity of pig meat produced as affected by a change in feed use.

The second part of this thesis consists of two articles concerning the economic implications of technology use in relation to production externalities. Article III, *Utility of phase feeding choices in pig farming*, aims to rank farmers' utility of using different protein ratios in feed use. Article IV, *Environmental regulations with focus on pig density restriction and farms' technologies*, aims to analyse effects of environmental regulations on intensive animal farming and the effects of technology use on the cost of altering production to comply with environmental regulation.

A major conclusion of this thesis is that an economically rational farmer considers the economic value of a specific technology that may improve animal welfare and that reduces production externalities simultaneously. However, the economic values and the benefits obtained from technologies vary depending on individual conditions at farm levels.

1.4 Disposition

Subsequent to the introductory part, the thesis is organised as follows. The next section presents the applied economic and the econometric methods throughout this thesis and a description of the data set and some of the limitations imposed by the available information are discussed. Section three discusses major results. Section four summarises some of the major conclusions this thesis. Section five discusses the contribution of this thesis to present literature, and the last section provides some ideas to further research.

2 Methods

The emphasis of this thesis is mainly of empirical nature. Farmers' decisions on production technologies from observed Swedish production conditions are modelled according to microeconomic theory. Estimations are conducted with various econometric standards methods. Thus, in order to justify applied economic, econometric, and evaluation methods it is necessary to be familiar with the underlying information used for each model. A short description of the data set and some of the limitations of each study due to lack of empirical information are therefore presented.

2.1 Economic methods

The first part of the thesis, articles I and II, deals with the assessment of technology values in production. The value of specific technologies is difficult to assess without considering production costs. However, given an appropriate specification of the production function, an approach is to consider technology effects on daily weight gain and feed conversion and to evaluate these effects as changes in profit. Hence, pig production is assumed to depend on pigs daily weight gain as affected by feed conversion and the available technology set. Although the opposite is also valid, feed conversion is affected by the state of pigs' daily weight and production technologies. Thus article I introduces the hypothesis of mutual dependence between a pig's growth and feed consumption. The definition of technologies improving animal welfare implies that pigs grow at a proper rate and feed consumption. This specification form allows us to observe technology impacts on animal welfare and to estimate the economic value of each technology in use.

Livestock production is a dynamic process. A farmer's decision on when to terminate a batch depends on the number of feeding days. An optimal replacement condition implies that a pig is kept in production until its average net value equals its marginal net value. The optimal replacement condition is necessary in order to evaluate technology effects when there are no additional benefits of keeping production an extra day. That allows the interpretation of changes in net profits as attributable to changes in technology use.

Stochastic processes are involved in livestock production that depend on animals' metabolism and management decisions, simultaneously. To some extent, there are some stochastic factors in production that are impossible to control. The impact of a technology on the quantity of pig meat produced varies. For instance, stress and infection problems in a batch may increase the variance of produced pig meat, while a high quality nutritional level in feed may reduce the variance of pig meat. Hence, when a farmer adopts a new technology he considers a technology effect on feed efficiency. Article II, states the farmer's maximisation problem as maximisation of expected utility of profits. The production function is specified as a conditional distribution of pig meat on feed use, where feed interacts with a technology set. The approach requires the assumption of a risk-averse profit maximising farmer *i.e.* a farmer's utility function is strictly concave, and he operates at positive marginal product of feed. However, partial technology effects on feed efficiency are ambiguously signed. A new technology has a positive or a negative effect on the expected quantity of pig meat, increasing the probability of obtaining a high or a low outcome of pig meat quantity as affected by feed use. The latter is equivalent to whether a specific technology increases or decreases variance of pig meat. The separation of technology effects on the expected pig meat production and its variance allows the specification of the stochastic production process. In addition, it also allows the interpretation of technology effects in terms of feed efficiency.

The second part of this thesis considers economic implications of technologies in relation to production externalities. When piglets are put into production they require a high protein diet to grow, which is consecutively adjusted towards a less protein rich diet after some growth production. An excess of protein content in feed implies an excess of nutrient contents in manure, which leads to externalities. During the production and storage period, manure causes ammonia volatilisation. After production, when manure is applied to croplands, the problem turns into nitrogen leakage. Hence, decisions on the adjustment of protein contents in feed affect the nitrogen leaching as well as the economic benefits of farmers. Thus the use of phase feeding, the adjustment of protein contents in feed as pigs grow affects the utility of farmer's profits and organic nitrogen application rates.

Article III is based on random utility functions that are utilising the approach of Revealed Preferences (RP). The RP-approach uses actual choices made by respondents to develop models of choice (Adamowicz, *et al*. 1994). Since the approach is based on actual choices the assumption of utility maximisation can be relaxed, that is, an underlying economically rational behaviour on actual made choices is not required. Randomness enters into the model, since all underlying information about a farmer's choice cannot be observed. For instance, underlying information on farmers' evaluation of environmental quality may be interesting when explaining the choice of phase feeding alternatives. In order to rank a utility set arising from different alternatives, random utility functions over farmers revealing the same phase feeding preferences are aggregated. The method enables me to simultaneously consider economic benefits and externalities from pig production, thereby justifying the use of phase feeding as an alternative solution to a production and environmental problem.

Production externalities that arise from individual farms are addressed by imposing a ceiling on geographic concentration and pig density levels. For pig farming, the environmental regulation on animal density per hectare allows an upper-limit of 10.5 pigs/ha considering 2.5 batches/year. That implies a maximal production of 2650 pigs/year per 100 ha. Thus, to comply with the pig density regulation, it is assumed that a farmer has two options. He can reduce pig density by increasing the number of feeding days or by reducing the number of pigs produced. In article IV, the farmer's profit maximisation problem is stated as a Lagrangian function, given a constraint on the pig density regulation level. The Lagrangian multiplier is interpreted as the cost of altering production to comply with changes in the pig density level. It is evaluated for changes in stable capacity use and for changes in replacement time. In theory model technologies are constant. However, in the empirical part of the study technology effects on cost of altering production are analysed across a sample of farm. The method allows the identification of the cost of altering production at individual farm levels, and empirically to identify the effects of technologies on these costs.

2.2 Econometric methods

In the empirical section of each article, econometric methods are applied to test the theoretical models. Empirical models of the first part of the thesis consist of production functions that are evaluated at constant prices. The effects of technologies on production are evaluated as if a technology is available or not.

In article I, production is modelled as a simultaneous equation system. The system is estimated using the three-stage-least-squares method (3-SLS). The 3-SLS method is a full information method that offers consistent and efficient estimates. Technology effects on daily weight gain and feed conversion are used in the evaluation of profits. The evaluation is based on constant prices and the average observed production time. Changes in profit are evaluated considering whether a specific technology is in use or not.

In article II production is specified as a Just and Pope production function. Pig meat production is specified as a function on piglets' weight, hours of labour and feed use interacting with a technology vector. The model specification allows the observation of a deterministic part explaining the expected production of pig meat and an additive stochastic part explaining the variance of production. The model is estimated in two stages by the ordinary-least-square method (OLS), correcting for heteroskedasticity due to panel data properties. When correcting for heteroskedasticity OLS estimates become consistent and efficient. Parameters values are used in the calculation of the expected pig meat quantity and its variance to evaluate feed efficiency given that a technology is available or not.

The model of phase feeding choice implies three utility alternatives to rank. However, when the data set is not well behaved, as in this case, the estimation of a three alternatives model turns into the estimation of a two-alternatives choice. That is a utility in differences model. Statistically, the random utility model is estimated as a bivariate probit model with the maximum likelihood method, (ML). The unobserved part of each utility is specified as a random term. Thus, utility is represented by the probability that an individual chooses the alternative bringing him the greatest utility.

In the calculation of the cost of altering production the Lagrange multiplier from optimality conditions is evaluated for two possible options, when changing stable capacity use and when changing replacement time. These are measures on the costs of altering production to comply with the pig density regulation, which are calculated for each observation. Model estimation is conducted in two steps. First, a production function is specified as a two-way error component model with fixed effects, factoring out farm- and time-specific effects due to panel data properties. Estimated parameter values are used in the calculation of costs (or profit loss) for each farm. In a second stage, a Tobit model is estimated with the ML-method to assess technology effects on the costs of altering production by reducing stable capacity use and by increasing replacement time. The Tobit model is a combination of a truncated and a univariate probit model specification. The dependent variables are latent variables generated by the classical linear regression model, which censures farms to be at the maximum level of the pig density regulation.

2.3 Data set and limitations

Information is available on production conditions for Swedish pig farms. In the sample, farmers participate in quality policy programs developed by Swedish Meats. During the studied period 1995–1997 farmers are in a transition period between the Scan-H program and the BIS program. The BIS program was developed in 1995, as an extension of the Scan-H program. The BIS program specifies in detail guidelines for breeding, animal health, and management. However, no more than approximately 40% of the total Swedish volume of pig meat is produced in accordance with the BIS program (Hoffmann *et al*., 1997), thereby implying a sample selection bias. Hence, estimated parameter values may not be representative for the entire Swedish pig industry. In 1995, the sample average is 3.4 batches/year, while the total pig industry production average is 2.5 batches/year (SJV, 2001).

The main data set is available in the RASP-management information system (Swedish Meats, 1997). It consists of production results for slaughter-pigs during

1995–1997. These are average observations per batch produced. There is an additional data set that includes a detailed description of the available technologies for each stable and each farm during 1995–1996. In the sample there are 99 farms, operating between one to eight stables, and these produce one to four batches per year. Additional information for farms such as crop production, soil clay content, manure handling, and hours of labour in pig production is obtained through a survey conducted during the spring 2000 (see appendix). The questionnaire was sent to 97 producers in the RASP records. However, only information for 61 farms matched the previous data set. Information on prices used in the evaluation of the different models, are obtained from Swedish Meats (1997), Brundin (1994), Agriwise (2000), and Statistics Sweden (2001). Information on weather is obtained from SMHI (1998).

As previously stated, the main objective of the thesis is to study the effects of technologies on pig production. Consequently, the next sections present how the technology set is selected on the basis of information in available literature on pig production. The technology set describes building design, feeding system, and managerial practices.

2.3.1 Building design

Selected technologies that describe building design are related to the control of climate conditions in the stable and box disposition. Climate conditions in the stable have a direct impact on pigs' state of health. Important aspects to control are the spread of infections and diseases, the noise level, temperature and dust, in a section as well as between sections in a stable. Inappropriate climate conditions in the stable have negative impacts on pigs' biological performance, such as a lower daily weight gain, increased feed consumption and a higher sensitivity to various kinds of diseases. Selected technologies to describe the control of climate conditions are air partition, ventilation system, evacuation of manure gas, and dimmer.

The pigs' near environment affects their behaviour and metabolism. For instance, good hygiene in the box is an indicator of pigs' welfare. Pigs that feel comfortable are capable of separating manure and bedding within the box, reducing infection risks and facilitating work (Olsson *et al*., 1994). Another welfare sign is the absence of tail biting. Beattie *et al*. (1996) show that an increase of the available space per pig in the box reduces tail biting. Technologies that explain box disposition are cross-trough boxes and trough length (in m/pig). Table 5 presents building design, variable definitions, expected impacts, and literature sources.

Table 5: Building design.

Factor	Variable definition	Impact	Source
Air partition	Dummy variable. Air partition is specified as no air contact between sections in the stable. D = 1, sections are located in different buildings or separated with air lock, D = 0 otherwise.	Reduces the spread of diseases between sections in the stable.	Ekesbo and Lund (1993) Boterman *et al*. (1995)
Ventilation system	Dummy variable. D = 1, vacuum ventilation system, D = 0 otherwise.	Precludes dry air, draught, and condensed drip on cold surfaces. There are fewer hygiene problems.	Lundeheim (1988) Wallgren *et al*. (1993)
Evacuation gas	Dummy variable. D = 1, manure gas evacuation in the stable and in culverts, D = 0 otherwise.	Regulates the concentration of toxic gases.	Simonsson *et al*. (1997)
Dimmer	Dummy variable. D = 1, dimmer, D = 0 otherwise.	Reduces the dust in the stable.	Nilsson *et al*. (1987) Dividich (1991)
Cross-trough box	Dummy variable. D = 1, cross-trough boxes, D = 0 otherwise.	Specially designed for wet feed. The manure area is larger than in long-trough boxes.	Rundgren *et al*. (1993) Olsson *et al*. (1994)
Trough length m/ pig	Continuous variable. It is a measure of available space per pig.	Measure of space allowance for pigs.	Randolph *et al*. (1981) Lindemann *et al*. (1988) Beattie *et al*. (1996)

2.3.2 Feeding system

The feeding system includes the use of by-products, phase feeding, and wet feed. Nutrients in feed have a direct impact on pigs' growth, and thereby on feed consumption. For instance, the use of by-products is a common and less expensive alternative source of nutrients. This technology, as well as the use of phase feeding, requires knowledge and experience of how to mix feed components, influencing the total cost of feed. The use of phase feeding implies an adjustment of protein content in feed as pigs grow. There are three phase feeding alternatives (Simonsson *et al.*, 1997; Stern and Simonsson, 1998). Phase feeding I is when the pig is fed at constant protein ratios during the entire production period. Phase feeding II and III imply a higher protein intake in the first growth stage to be gradually reduced in remaining stage(s). The use of wet feed enables producers to alternate between the use of cereals and by-products in order to balance nutrient levels and to reduce costs. Table 6 presents the feeding system, variable definitions, expected impacts, and literature sources.

Table 6: Feeding system.

Factor	Variable definition	Impact	Source
By-products	Dummy variable. D = 1, by-products such as starch, potato, bread, chips, etc. D = 0 otherwise.	Uncertainty regarding energy and protein content. Serves as a low-cost feed alternative.	Henry (1992) Thomke *et al.* (1995) Simonsson *et al.* (1997) Andersson (1997)
Phase feeding II-III	Dummy variable. D = 1, adjustment of protein contents in feed as pig grows, D = 0 otherwise	Reduce nutrient contents in manure.	Simonsson *et al.* (1997) Stern *et al.* (1998)
Wet feed	Dummy variable. D = 1, wet feed, D = 0 otherwise.	Facilitates work and enables a high level control of the feeding process.	Maton *et al.* (1991) Myyawaki *et al.* (1996)

2.3.3 Managerial practices

Managerial practices consist of decisions at production and herd levels. At the production level, decisions on disinfecting between batches, how to sort litters, and when to start a batch are considered. Disinfecting more than once a year may be a sign of infection problems in a stable. It may take up to two weeks to clean and disinfect the stable. Sorting piglets at the start of a batch enables more homogenous litters, improving the capacity use of the stable and reduces the variance of daily weight gain in a box. Starting a batch during the summer season poses some problems. Pigs tend to feel languid and lose appetite when outside temperatures exceed 22°C (Southern *et al*., 1989; Nienaber *et al*., 1996).

At the herd level, decisions are made on whether to participate in quality policy programs, and what kind of herd to operate. There are three basic types of herds. These are integrated, intermediate and specialised herds. In integrated herds the entire production process takes place at the same farm, implying fewer stress factors for pigs. In the case of intermediate herds, piglets are supplied from one herd, by contrast to specialised ones, where piglets originate from several suppliers. Operating an intermediate herd demands additional skills in the negotiation process with the supplier of piglets and require proper coordination between both producers. Table 7 summarises managerial practices.

Table 7: Managerial practices.

Factor	Variable definition	Impact	Source
Disinfecting	Dummy variable. D = 1, disinfecting between batches more than once a year, D = 0 otherwise.	A signal of infection problems. It is time-consuming.	Wallgren *et al*. (1993)
Sorting litters	Dummy variable. D = 1, sorting by weight and sex, D = 0 otherwise.	Procures homogenous litters.	Simonsson *et al*. (1997)
Number of summer days	Continuous variable in days. It indicates that a batch is started during summer days with outside temperatures exceeding 22° C.	Pigs lose appetite.	Southern *et al*. (1989) Nienaber *et al*. (1996)
BIS program	Dummy variable. D = 1, BIS quality policy program, D = 0 Scan-H program.	Demands appropriate technologies and managerial practices.	Swedish Meats (1996) Hoffmann *et al*. (1997)
Intermediate herd	Dummy variable. D = 1, intermediate herd, D = 0 integrated and specialised herds.	Purchases of piglets from one herd. It is difficult to obtain uniform litters.	Simonsson *et al*. (1997)
Integrated herd	Dummy variable. D = 1, integrated herd, D = 0 Intermediate and specialised herds.	Reduces infection risk. Own supply of piglets.	Simonsson *et al*. (1997)

2.3.4 Data sets for articles I-IV

Given the main data set a subset of data is created for each of the articles depending on the subject to analyse. In article I there is information on 469 batches from 99 farms during 1995−1996. These are average observations per batch on daily weight gain, feed consumption, piglets' weight, and the number of feeding days. Each observation represents average pig production per batch. Hence, an observation represents the average production performance of a pig. The data set imposes some limitations in the estimation of the optimal replacement time that ultimately would require daily observations per batch. Hence the replacement time is approximated with the sample average replacement time per batch.

Another important limitation in the data set is that changes in long run investments due to specific requirements for building and building equipment are not available. Consequently, the economic benefits of some technologies that may require additional investments may therefore, in some cases, be slightly overstated. However, several technologies such as sorting, operating intermediate herds, phase feeding may have a rather limited impact on long run investments.

Results are evaluated at constant prices for pig meat and feed, while prices of piglets vary. Producer prices depend on the lean meat percentage. For an average carcass weight of 81.2 kg/pig, average lean meat percentage is 60.12% in the range of 62.3% – 57.4%, which corresponds to the best-paid interval in the producer price system. The rather small sample variation of lean meat percentage causes all sample observations being at the best-paid interval. The price of piglets varies depending on piglets' initial weight. Information on prices is obtained from Swedish Meats, in 1996 price level. The data set includes additional weather information from SMHI (1998). That is used to estimate effects of extremely warm summer days on pig production.

In article II, the data set consists of 151 observations for 61 farms during the period 1995−1997. The reduction of number of observed farms depends partly on the inclusion of the variable hours of labour, which is obtained from the survey. Observations are calculated as yearly production rather than batch production. For each farm, year production averages are calculated to avoid unbalanced panel data properties. Each farm produces different number of batches per year, in different stables, implying heteroskedasticy problems within and between farms. Information on prices is the same as in article I. No measure of the coefficient of relative risk aversion is available for Swedish pig farmers. A more accurate measure of the risk aversion coefficient would be desirable than what is available from the literature. However, empirical measurements of risk aversion for Swedish pig farmers is beyond the objectives of this thesis.

The data set for articles III and IV consists of 610 observations for 61 farms during 1995−1997. Observations are calculated in pig units per hectare. That measure considers the number of batches per year, the number of pigs per batch, and the available area of land. Information on farm characteristics and technologies is highly aggregated. Variables in the model are defined as profit in pig units/ha and organic nitrogen application rates/ha. Observations on farm characteristics are rather constant across farms due to government regulations and geographic concentration of farms. Most farms in the sample are located in the counties of Östergötland and Skaraborg, the middle region of Sweden. The variable nitrogen application rate is calculated as the share of organic nitrogen in manure produced according to a study of Jakobsson *et al*. (1998). A more representative measure of organic nitrogen application rates could be the share of organic nitrogen on farms' total nitrogen application rates. However, this information is not available in the data set. An important distinction in article IV is that the data set specifies a technology set that is used to estimate technology effects on the cost of altering production to comply with changes in the pig density regulation.

Prices of commercial fertiliser for nitrogen, phosphorus, and potassium (Agriwise, 2000) are used in the calculation of manure income. Information on the cost of manure spreading is obtained from a study of Brundin (1994). The price of feed is from Agriwise (2000), and it varies with respect to the choice of phase feeding. Information on prices piglets' weight and carcass weight is the same as in articles I and II.

The next section discusses some major results for each article in this thesis. First, results are discussed in terms of the relation between the economic value of technologies and animal welfare, and technology effects on feed efficiency. Subsequently, the discussion of results is extended to consider technology choice and economic aspects on production externalities and environmental regulations.

3 Major results

Economically rational behaviour is characterised by the ability to improve profits as a consequence of improve productive performance in arbitrary agricultural enterprise. However, even if an economically rational farmer disregards animal welfare when selecting technologies, an appropriate choice of the technology set, has consequences for animal welfare. Studies on animal breeding recognise the importance of specific technologies to control pigs' welfare during production, regardless of the economic value. Results presented in article I show that a positive technology effect on profits arise when a positive effect on pigs' total weight that overwhelms a positive or negative impact on total feed consumption. Most of the technologies included in the model are designed to promote animal welfare as well as the biological performance in the production process. Table 8 summarises results.

Table 8: Relationship between technology effects on pig production and profit.

	Positive technology effects on pig production	Negative technology effects on pig production
Positive technology effects on profit	Ventilation system Evacuation gas Cross-trough box Wet feed Dimmer* Trough length Disinfecting* Number of summer days Intermediate herd Integrated herd	
Negative technology effects on profit	By-products	Air partition BIS program

*The parameter value is not found to be statistically significant.

As demonstrated in table 8, most of the technologies that have a positive impact on pig production, yield a positive effect on profit. The use of ventilation system, evacuation gas, cross-trough box, and wet feed increase total weight and reduce feed consumption, having positive effects on profit. The use of dimmer, disinfecting, intermediate and integrated herds, increasing trough length by 10 cm and summer days by 1 day, increase a pig's weight and feed consumption. Even these technologies have a positive net effect on profit. The use of by-products increases total weight as well as feed consumption, implying a higher marginal cost of feed than the additional income received from weight produced. However, it is recognised that the use of by-products is to reduce feed costs. In the study the cost of by-products is slightly overestimated since the evaluation is based on the price of conventional feed. Participation in the BIS program and the use of air partition have negative effects on total weight implying an economic loss. Negative results of participating in the BIS program may be explained due to time lags in the adoption of a new technology. On the other hand, most of the technologies required by the BIS program indicate positive effects on pig production, and thereby on profit. Finally, the analysis shows that the use of air partition, which is imposed by animal welfare legislation to promote animal welfare, results in a negative effect on biological performance and profit.

Another interesting economic problem relates to the selection of technologies and the consequences for optimal conversion of input into output. Given that a farmer maximises the expected utility of profits, results from article II suggest that the effects of technologies on feed efficiency depend basically on two relationships. First, the relationship between the expected pig meat quantity and the level of risk aversion is important as demonstrated in theory model. Secondly is the relationship between the expected pig meat quantity and its variance play a major role. Given an increase in feed use, the higher the level of risk aversion, the greater is a positive technology effect on the expected pig meat. However, the positive technology effects on expected pig meat vary with respect to an increasing or decreasing impact on the variance of pig meat. This latter result is even valid for a risk neutral producer. Therefore, a technology should be adopted when it has a positive effect on the expected quantity of pig meat and it decreases the variance. Furthermore, when a positive effect of a technology overwhelms an increase in variance it should also be adopted. Table 9 summarises the effects of technologies on feed efficiency.

Table 9: Technology effects on feed efficiency.

	Increase in expected pig meat production	Decrease in expected pig meat production
Decrease in variance of pig meat production	Ventilation system Evacuation gas Wet feed Disinfecting†	
Increase in variance of pig meat production	Cross-trough box Intermediate herd Integrated herd†	Air partition* By-products BIS program* Sorting

†The parameter value in the risk model is not found to be statistically significant.

*The parameter value in the deterministic model is not found to be statistically significant.

In the second part of the thesis the focus is on the economic implication of technology use in relation to production externalities. Article III ranks farmers' utility of phase feeding choices. The greatest utility from the use of phase feeding is obtained for the alternative that brings the largest profit to farmers and the smallest organic nitrogen application rate. The greatest utility is obtained from phase feeding III, where protein content in feed is reduced at three different growth stages. Given the sample, farmers that use phase feeding III also produce at a higher pig density level than producers that use a constant protein ratio in feed. Hence, it appears that if the utility attributable to adjusting protein content in feed becomes even more important when farmers are land-constrained. Similar results are found in Boland *et al*. (1998). Thus, results indicate that the use of phase feeding offers an economic incentive to farmers to reduce production externalities.

However, environmental regulations intended to reduce production externality levels on pig farms do usually not take into account production conditions at the individual farm. For farms that exceed pig density levels the adjustment of production to comply with the pig density level implies a cost. Results from article IV indicate that farms that produce above the pig density restriction experience a lower cost of reducing pig density by increasing replacement time compared to reducing stable capacity use. These farmers are land-constrained and show a lower profitability per pig compared to farmers that produce below the pig density regulation. It seems that farmers that produce above the pig density regulation compensate a low profitability per pig with a higher stable capacity use. The effects of different technologies on the cost of complying with changes in the regulation by altering production through a reduction of stable capacity use and increase replacement time are presented in table 10.

Table 10: Technology effects on the cost of changing pig density levels.

		Reduce stable capacity use	
		Reduce cost	Increase cost
Increase replacement time	Reduce cost	Air partition By-product Intermediate herd Sorting‡	Disinfecting
	Increase cost	Ventilation system* Phase feeding II-III†	Evacuation gas Integrated herd‡

*The parameter value in the stable capacity use model is not found to be statistically significant.

†The parameter value in the replacement time model is not found to be statistically significant.

‡The parameter value is not found to be statistically significant.

As shown in table 10, the cost of reducing pig density is reduced by the use of air partition, by-products, sorting litters and by operating intermediate herds. Results suggest that these technologies reduce the cost of reducing pig density, when reducing stable capacity use or when increasing replacement time. That means that the value of each of these technologies becomes higher when pig density is reduced. That seems reasonable for the use of air partition and sorting litters. However, the use of by-products is a cost-saving technology no matter the pig density level at the farm. On the other hand, the use of evacuation gas and operating an integrated herd increases the cost of reducing pig density. A possible explanation is that the substantial economic benefits from using these technologies are lessened when pig density is reduced, resulting in a reduction in their economic value. Disinfecting between batches becomes more valuable when replacement time is increased. If the production period is expanded, the cost of time that is necessarily required for disinfecting becomes less valuable. However, the use ventilation system and phase feeding becomes more valuable when the stable capacity use is reduced. The effects of these technologies seem to be more effective when there are fewer pigs in production compared to the effects when the stable is operating at a full capacity use. As a result, the benefits of different technologies vary depending on pig density levels and various strategies for adjusting production. Consequently, given decisions on how to comply with pig density regulation, a farmer needs to consider the benefits of specific technologies in relation to pig density levels and actual conditions on the farm.

4 Major conclusions

Decisions regarding technologies affect productive performance and thereby profits. The impacts of several technologies on output levels and input use have direct consequences for animal welfare, making the technological benefits and economic values vary. Hence, an economically rational farmer selects a technology set considering the effects of a technology on profit. For this choice to be economically rational, it must be based on production conditions at the individual farm. In this study, many of the technologies are introduced due to legal regulations on animal welfare or in adherence to participation in quality programs that in detail specify how to manage production. However, according to this study, not all of these technologies imply improvements in biological performance or bring economic benefits to farmers. The reason is that production conditions across farms vary, and the benefits of different technologies vary. Nevertheless, an economically rational choice of a technology often conforms to improvements in animal welfare, which often has a positive impact on the economic value of a technology.

When a farmer selects a technology he considers the benefits of it. A technology that has a positive effect on profit is likely to be adopted. Hence, the farmer experiences an economic incentive for the adoption of a technology that increases utility of profit and that reduces production externalities, simultaneously. Such forms of technology adoption may be regarded as a possible solution to an economic and environmental problem. However, according to results some farmers compensate a low profitability per pig by increasing the number of pigs produced, which also implies an increase in pig density level. Given that land is constrained, an increase in pig density may imply an increase in production externalities. The negative effects of externalities on the environment require environmental regulations at farm levels. However, environmental regulations typically do not always consider production conditions at the individual farm. That implies a cost of altering production from individual level to the regulation level. Now, if some farmers already compensate a low profitability per pig by increasing pig density the additional cost of altering production due to an environmental regulation further reduces the economic results.

The production of externalities can also be viewed as a misuse of inputs, such as feed waste. That is equivalent to state that production does not operate at an optimal level of feed use and that the farmer does not behave economically rational. However, livestock production implies externalities such as ammonia volatilisation and nitrogen leaching irrespective of whether a farmer is economically rational or if he is land-constrained. The study shows that the selection of an appropriate technology set tends to reduce externalities originating from manure production and in many cases improve animal welfare. Hence, considering that the benefits and economic values of a specific technology vary, farmers may in some cases have an economic incentive to consider animal welfare and production externalities when selecting an appropriate technology set.

5 Contributions to present literature

There are three major contributions emerging from this thesis; the first concerns with the recognition of specific technology values; the second is in relation to profitability, animal welfare, and environmental regulations; and the third refers to modelling real-world conditions.

Model specifications in article I and II drawn on studies by Chavas *et al*. (1985) and Babcock and Hennessy (1996) respectively. However, production functions in the models have been adjusted to consider technology effects. The novelty in article I is the simultaneous dependence between the daily weight gain and feed consumption as affected by a technology set. This specification form allows the identification and evaluation of specific technology effects on biological performance and profits. The novelty in article II is the specification of the production function interacting with feed use and a technology set. That allows the observation of technology effects on the expected pig meat quantity and on its variance, in relation to feed efficiency.

There are two main remarks about contributions to present literature from these studies; the first is that new specification forms, including technologies, do not change previously stated optimality conditions; and the second is that the methods are valid to evaluate any dynamic production that can be controlled by input use, time and technologies.

In article III the idea of using phase feeding in pig production, recognised by Boland *et al*. (1998, 1999), is expanded to even consider farmers' utilities of phase feeding choices. That allows the analysis of farmers' utility of profits and organic nitrogen application rates simultaneously, offering a feasible solution to an economic and an environmental problem for pig farms. Similarly, in article IV, the statement in Hötte *et al*. (1995) that few studies take into account individual farm characteristics in relation to environmental regulation, has been expanded to analyse the cost of altering production to comply with the pig density regulation and to identify the effects of technologies on these costs.

A general approach throughout this thesis is that economic and biological aspects have been synthesised in order to reflect real world production conditions at farm and enterprise levels. Microeconomic modelling of real-world farm conditions is found to provide a good foundation for the understanding of livestock production and the implications for the environment.

6 Further research

An immediate question arising from the first part of this thesis is: To what extent should animal welfare be improved? It seems that animal welfare can be considerably improved. Nevertheless, there are several real-world constraints such as technological requirement and the economic conditions at a farm level. If farmers enjoy animal production and that farmers consider the economic benefits of producing animals, there might be a mutual dependence between profits and animal welfare. Consequently, the optimal design of management- and information systems, buildings and an appropriate composition of the technology set considering production conditions at the individual farm level are essential areas for further research. The implications for the long run investments attributable to investments in building design and building equipment is another vital area of when properly evaluating new systems design.

Another interesting issue for further research concerns rational decisions regarding optimal input use in order to reduce production externalities. Nutrient overloads may be controlled through an optimal feed use given appropriate technologies. To some extent such strategy implies improved control of the quality and the quantity of nutrients in manure. An increasing degree of certainty in nutrient contents in manure production would give a better use of manure as an input onto cropland. Thereby, increasing the substitutability between the commercial fertiliser and organic manure increases. The use of organic manure implies additional uncertainty compared to commercial fertiliser, hence, the design of optimal incentive mechanisms for effectively using organic manure and thereby reducing production externalities is yet another area for further research.

As mention before, an economically rational behaviour induce adoption of animal welfare improving technologies, but only in the sense of considering the private economic benefits of production. However, it is possible that farmers may improve animal welfare at the expense of increasing production cost, only if there is a demand and a stated willingness among consumers to pay for animal welfare. However, the optimal level of investments in animal welfare depends on whether the demand for animal welfare is stable in a short run and/or a long run perspective. Hence the stochastic natures of demand conditions as well as the interaction with a stochastic supply are vital issues for further research.

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